



## **The stereospecific triacylglycerol structures and fatty acid profiles of human milk and infant formulas**

Straarup, Ellen Marie; Lauritzen, Lotte; Faerk, Jan; Høy, Carl-Erik; Michaelsen, Kim Fleischer

*Published in:*  
Journal of Pediatric Gastroenterology and Nutrition

*DOI:*  
[10.1097/01.mpg.0000214155.51036.4f](https://doi.org/10.1097/01.mpg.0000214155.51036.4f)

*Publication date:*  
2006

*Document version*  
Early version, also known as pre-print

*Citation for published version (APA):*  
Straarup, E. M., Lauritzen, L., Faerk, J., Høy, C-E., & Michaelsen, K. F. (2006). The stereospecific triacylglycerol structures and fatty acid profiles of human milk and infant formulas. *Journal of Pediatric Gastroenterology and Nutrition*, 42(3), 293-299. <https://doi.org/10.1097/01.mpg.0000214155.51036.4f>

# The stereospecific triacylglycerol structures and fatty acid profiles of human milk and infant formulas

Ellen Marie Straarup, PhD<sup>1</sup>, Lotte Lauritzen PhD<sup>\*2</sup>, Jan Faerk, PhD<sup>3</sup>, the late Carl-Erik Høy,  
PhD<sup>1</sup> and Kim F. Michaelsen, PhD<sup>2</sup>.

<sup>1</sup>*Centre of Advanced Food Studies, BioCentrum-DTU, Biochemistry and Nutrition Group,  
Technical University of Denmark*

<sup>2</sup>*Department of Human Nutrition, The Royal Veterinary and Agricultural University,  
Denmark*

<sup>3</sup>*Pediatric Department, Holbaek Hospital, Denmark*

## **Mailing address:**

\*Address correspondence and reprint requests to Dr. Lotte Lauritzen, Department of Human  
Nutrition, The Royal Veterinary and Agricultural University, Rolighedsvej 30, 1958  
Frederiksberg C, Denmark.

Phone: +45 3528 2508, Fax: +45 3528 2483, e-mail: [ll@kvl.dk](mailto:ll@kvl.dk)

Source of support: This study was financed by FOETEK - The Danish Research and  
Development Program for Food and Technology.

## 1 ABSTRACT

2 **Background:** The stereospecific structures of the triacylglycerol molecules in human milk  
3 differ from that of cow's milk and vegetable oils, which are the fat sources used in infant  
4 formula. In human milk, palmitic acid (16:0) is predominantly esterified in the *sn2*-position,  
5 whereas vegetable oils or cow's milk fat contain most of their 16:0 in the outer positions of  
6 the triacylglycerol molecules. Furthermore, human milk contains long-chain polyunsaturated  
7 fatty acids (LCPUFA), which are not present in either cow's milk or vegetable oils.

8 **Methods:** By standard lipid analysis procedures we examined the triacylglycerol structures  
9 and fatty acid profiles of fats from 28 infant formulas or formulas for special indications  
10 available on the Danish market 1999-2003.

11 **Results:** The total fatty acid compositions of the formulas showed a 16:0 content almost  
12 similar to human milk, whereas the content in the *sn2*-position was considerably lower. The  
13 content of oleic acid was found to be equal to or higher than in human milk in 21 out of 28  
14 formulas; whereas the content in the *sn2*-position was higher in all but one formula. Most  
15 formulas had linoleic acid levels considerably above that of human milk. LCPUFA  
16 (arachidonic acid and docosahexaenoic acid) were present in all preterm formulas, but only in  
17 three of the term formulas.

18 **Conclusion:** We found that most of the examined infant formulas, both preterm and term as  
19 well as special formulas, had stereospecific structures and fatty acid profiles that differed  
20 considerably from that of human milk.

21

22 **KEYWORDS:** Infant formulas, fat, human milk, triacylglycerol structure, polyunsaturated  
23 fatty acid  
24

## 1 INTRODUCTION

2 During the last decades there has been increasing interest in the fatty acid composition of  
3 infant formulas (1,2). The interest has focused on the content of polyunsaturated fatty acids  
4 (PUFA), especially the balance between n-3 and n-6 PUFA and the possible need to add the  
5 long-chain PUFA (LCPUFA), docosahexaenoic acid (22:6n-3, DHA) and arachidonic acid  
6 (20:4n-6, ARA). Recently, the importance of the stereospecific triacylglycerol structures has  
7 been demonstrated (3,4). The target has been to produce an infant formula with a fat content,  
8 composition and structure close to that found in human milk. Using a blend of different fats,  
9 mainly vegetable oils, it has been possible to match the overall fatty acid composition of  
10 human milk, but not the triacylglycerol structure.

11 Fat absorption is higher from human milk than from infant formula, despite the  
12 similarities between the fatty acid profiles (5). This may partly be explained by the unique  
13 triacylglycerol structure of human milk. Palmitic acid (16:0) is abundant in human milk and  
14 is an important source of energy. Most of the 16:0 in human milk is located in the *sn*2-  
15 position of the triacylglycerol molecules (6), in contrast to cow's milk and vegetable oils  
16 which have 40 % (7) and 5-20 %, respectively, of the 16:0 in the *sn*2-position (8). Therefore,  
17 hydrolysis of human milk fat result in 16:0 mainly as *sn*2-monoacylglycerol, which are well  
18 absorbed (7,9). In contrast, after hydrolysis 16:0 from vegetable oils will be present as free  
19 fatty acids, which tend to bind calcium and form insoluble calcium-soaps in the intestine that  
20 may cause constipation

21 LCPUFA are present in human milk but have not until now been added to the  
22 majority of standard infant formulas available in the Danish market. DHA is important for  
23 development of the nervous system (2) and ARA is the precursor of eicosanoids (10), which  
24 are local mediators involved in, for example, the regulation of the immune function and  
25 platelet aggregation. It is presently recommended that the content of the precursors for these

1 LCPUFA, linoleic acid (18:2n-6, LA) and  $\alpha$ -linolenic acid (18:3n-3, LNA), are 500-1200  
2 mg/100 kcal and above 50 mg/100 kcal, respectively, to the infant formulas without  
3 LCPUFA and that the ratio of LA to LNA should be between 5 and 15 (11). It is generally  
4 agreed that LCPUFA should be added to formulas for preterm infants, whereas no agreement  
5 has been reached on whether to add LCPUFA to formulas for term infants (11,12,13).

6 The aim of this study was to describe the fatty acid compositions and the  
7 stereospecific triacylglycerol structures of a selection of formulas in the market in Denmark,  
8 to compare these with human milk, when appropriate, and to discuss some of the  
9 consequences of these issues. Our focus was on the content and position in the  
10 triacylglycerols of 16:0, oleic acid (18:1n-9), LA, LNA, DHA and ARA. Furthermore, we  
11 studied structure and profile differences of the fat from formulas with different applications  
12 (for premature, term infants or infants with various disorders), with special focus on the  
13 presence of medium-chain fatty acids (MCFA, 8:0 and 10:0).

## 15 MATERIALS AND METHODS

16 Twenty-eight different formulas were analyzed. Five of the formulas were for premature  
17 infants; eight for term newborn infants (term infant formulas), four were follow-on formulas  
18 for infants >4 mo of age, and 11 were special formulas for infants and young children with  
19 different disorders (Table 1). The fatty acid profiles and structures were compared to values  
20 from different types of human milk. We analysed a pooled sample of human milk derived  
21 from mothers delivering prematurely before the gestational age of 34 weeks. The mothers  
22 emptied both breasts with the help of an electrical pump and each mother collected the milk  
23 in a 24 hour pool. The milk was collected between the second and fourth week after delivery.  
24 Furthermore, we included in Table 3 sets of values from the literature (6,9,14). We also

1 analysed cow's milk (standard full fat pasteurized cow's milk bought during the month of  
2 February).

3 The formulas were purchased and analyzed between 1999-2003. Seven of the  
4 formulas were purchased and analyzed both in 1999 and in 2003 (Allomin-1, Allomin-2,  
5 soured Allomin, Baby Milk, Enfalac, Nutramigen and NAN H.A). These analyses gave  
6 similar results with respect to profile and structure for all except one of the formulas. In 2003  
7 Enfalac had increased proportions of 18:1n-9, ARA and DHA and decreased proportions of  
8 lauric acid (12:0) and LA compared to that in the 1999 formula. This paper presents the  
9 results of the most recent analyses.

#### 11 **Formula fat analysis**

12 Powdered formulas were dissolved in water (250 mg formula/ml water), whereas liquid  
13 formulas, human milk and cow's milk were extracted from their origin. The fats were  
14 extracted by the Folch procedure (15) and fatty acids were dissolved in heptane. Fatty acid  
15 methyl esters (FAME) were prepared from total lipids through transesterification catalysed  
16 by KOH in methanol (16). The FAME were analysed by gas-liquid chromatography using a  
17 Hewlett-Packard 5890 series II Chromatograph with flame-ionisation detection (Hewlett-  
18 Packard GmbH, Waldbronn, Germany), and a fused silica capillary column (SP-2380, 60 m,  
19 ID 0.25 mm, Supelco, Bellefonte, PA). Helium was used as carrier gas. A split ratio of 1:11  
20 was applied in the injector. The column flow was constant at 1.2 mL/min. Initial oven  
21 temperature was 70 °C for 0.5 min and temperature programming was as follows: 15 °C/min  
22 to 160 °C, 1.5 °C/min to 200 °C, which was maintained for 15 min followed by a rate of 30  
23 °C/min to 225 °C, which was then maintained for 5 min. FAME peaks in the chromatogram  
24 (from octanoic acid (8:0) to DHA (from 4:0 for cow's milk)) were identified from external

standards (Nu-Chek-Prep, Inc. Minnisota, USA). The chromatogram areas of FAME with fewer than 12 carbons were corrected by response factors.

Regiospecific analyses of the formula fats were performed by degradation of the triacylglycerol molecules with allylmagnesium bromide as Grignard reagent (17). The *sn*2-monoacylglycerol fraction was isolated by thin-layer chromatography on boric acid-impregnated thin-layer chromatography-plates developed twice (2\*60 min) in chloroform:acetone (90:10 v/v), methylated, and analysed by gas-liquid chromatography. The fatty acid profiles of triacylglycerol and the *sn*2-position (Tables 2-4) are given as the distribution in wt% of all fatty acids (set to 100 %). The relative proportion of specific fatty acids in the *sn*2-position of the triacylglycerol molecule was calculated as:  $(M/T*3)*100$ , where M is the percentage of the fatty acid in the *sn*2-position and T is the percentage of the fatty acid in triacylglycerol (18). Data for the fatty acid profiles represent the mean of two determinations, whereas the analyses of the *sn*2-position represent the mean of three or four determinations. The standard error of the mean (SEM) was <3 % for fatty acids in triacylglycerol and <5 % for the *sn*2-monoacylglycerols.

## RESULTS

The fatty acid profiles and the *sn*2-fatty acids of the analysed infant formulas were compared with that of a range of human milk values and cow's milk (Table 2-4). Values market in bold are higher than the range found in human milk and values market in italic are lower. In general, the content of 18:1n-9, LA and LNA were higher in the infant formulas than in human milk both in total fatty acids and in the *sn*2-position. The content of MCFA was more than 20 fold higher than in human milk in six of the formulas: two preterm, two for use in malabsorption, and two for use as energy supplement. DHA was detected in seven

1 out of the 28 formulas, and in the *sn*2-position of two, whereas ARA was detected in eight  
2 formulas and in the *sn*2-position of six.

3 The ratios of LA to LNA in all of the formulas and cow's milk were within the  
4 interval recommended for standard infant formula of 5:1 to 15:1 (Tables 2-4), except  
5 Pregestimil, Super Soluble Duocal, Generaid Plus, Neocate and Therapeutic milk (all special  
6 formulas), which all had ratios >15:1. The proportions of LA in preterm infant formulas were  
7 about twice that in human milk, whereas that of LNA was similar to or twice that in human  
8 milk, resulting in LA-to-LNA-ratios that in most of the formulas were higher than in human  
9 milk.

## 10 11 **DISCUSSION**

12 Most infant formula fats are based on mixtures of vegetable oils or a blend of cow's milk fat  
13 and vegetable oils that to some extent mimic the fatty acid profile of human milk, as observed  
14 in the present study. However, the stereospecific structure in the formulas differed  
15 considerably from that in human milk. Most (about 75 %) of the 16:0 in human milk was  
16 located in the *sn*2-position, whereas most of the 16:0 in the formulas was located in the outer  
17 positions of the triacylglycerols (75-97 %). Comparison of infant formulas and human milk  
18 showed that 18:1n-9 replaced 16:0 in the *sn*2-position, as in vegetable oils (e.g. rapeseed and  
19 palm oils). This indicates that the largest part of the fat used in the formulas was of vegetable  
20 origin, except for Baby Milk, which was primarily based on cow's milk fat.

21 The human milk values we have used for comparison show a quite constant fatty acid  
22 pattern, despite the types of human milk being quite different (preterm milk, colostrums and  
23 mature milk). As expected the largest variation was in the content of DHA which is highly  
24 dependant on the mothers intake of DHA (19).



1           Constipation is more often observed in formula fed infants than in breast-fed infants  
2 (20). The structure differences between infant formula fats and human milk is one of the  
3 major reasons for the formation of insoluble calcium-soaps in the intestine. Betapol (Loders  
4 Croklaan, Wormerveer, The Netherlands) is a synthetic fat produced to mimic human milk  
5 fat both in total fatty acid profile and in structure (45 % of the 16:0 in the *sn2*-position).  
6 Studies with Betapol and other structured human milk substitutes showed that fats rich in  
7 *sn2*-16:0 compared to fats with a lower proportion of the 16:0 in the *sn2*-position improved  
8 absorption of 16:0 and calcium and reduced the excretion of calcium-soaps in the faeces of  
9 preterm infants (3), term infants (4) and rats (21). These studies support a beneficial  
10 physiological effect of the specific structured triacylglycerols on fat and calcium absorption.  
11 However, problems with calcium soap formation can also be solved by substituting 16:0 with  
12 other fatty acids, *e.g.* 18:1 n-9, as in many of the infant formulas, or with medium chain fatty  
13 acids (MCFA.).

14           High proportions of MCFA were found in special formulas for infants with  
15 malabsorption, lymphatic disorders, renal disease, liver disease (Pregestimil, Monogen, Super  
16 Soluble Duocal and Generaid Plus), and for preterm infants (PreNAN, Enfalac). These were  
17 added primarily instead of 16:0 as a readily available energy source. Infants with  
18 malabsorption can easier degrade, absorb and transport MCFAs than fatty acids of longer  
19 chain length. MCFAs are absorbed mainly to the portal vein and transported directly to the  
20 liver for  $\beta$ -oxidation (22). Formation of insoluble calcium-soaps in the intestine is low to  
21 non-existing, when MCFAs replace 16:0, due to the higher absorption (23,24). The  
22 nutritional value of special formulas with a high content of MCFA may be increased by  
23 addition of LCPUFA, possibly even further if the fat is structured (3). LCPUFA absorption  
24 has been shown to be improved in rats with malabsorption, if LCPUFA is supplied in fat with

MCFA in the outer positions and LCPUFA in the *sn2*-position (25,26) and so have fat utilisation and nitrogen retention in piglets (27).

The LA and LNA content of infant formulas are believed to cover the need of n-6 and n-3 LCPUFA in term infants through elongation and desaturation to ARA and DHA.

According to the current Nordic recommendations for infants 6-11 months of age the dietary intake of n-6 and n-3 PUFA should supply at least 4.0 % and 1.0 % of the energy intake,

respectively (28). Since the fat content of breast-milk and formulas constitutes about 50 % of the energy, this is equivalent to a n-6 and n-3 PUFA content of approximately 8 and 2 wt%,

respectively. Only four of the formulas in our study were found to have LNA content of

around 2 wt%. The ESPGHAN Committee on Nutrition (29) and the Scientific Committee on

Food (15) recommend that the ratio of LA to LNA in infant formulas should be 5-15. This

recommendation was made in the absence of data on functional or clinical outcomes (30).

Lowering the ratio of LA to LNA from 10:1 to 5:1 in formula fats resulted in modest increase

in plasma DHA, but with no detectable effect on visual acuity or growth rate (30). Most of

the formulas were found to have a high LA content well above that in human milk. A few of

the formulas, mostly special formulas intended for infants with special needs, had a very high

content of LA and ratios of LA to LNA between 17-55:1. Recent studies indicate that DHA

formation is inhibited by a high supply of LA (31,32). Therefore, there may be a need to

decrease the LA content, or supply LCPUFA, in order to meet the n-3 LCPUFA needs in

infants. However, the ratio of LA to LNA in infant formulas has improved since we analysed

infant formulas in the Danish market in the mid 1990s (33).

Only seven of the 28 infant formulas contained DHA and only eight of them had

ARA. In human milk 55 % of DHA was found to be specifically located in the *sn2*-position

of the triacylglycerol. Of the seven infant formulas that contained DHA, only PreNAN and

Enfalac had high levels in the *sn2*-position (34-50 %). Preterm infants have significantly

1 lower ARA and DHA status than full-term infants, because they do not receive the  
2 intrauterine supply of these fatty acids during late pregnancy (34). Dietary deficiency of ARA  
3 and DHA has therefore become an issue for the nutrition of preterm infants. Our results  
4 showed that the contents of these fatty acids in the formulas were similar to or lower than in  
5 human milk in four out of five formulas for ARA, and in all the preterm formulas for DHA.  
6 However, compared to other countries Danish mothers have a high n-3 LCPUFA intake and,  
7 thus, high levels of DHA in their milk (2).

8       The ratio of LA to LNA and the presence of LCPUFA in some of the formulas  
9 demonstrate that an improvement of the fatty acid profiles of the infant formulas has taken  
10 place over the last decades, although the content of LNA is still low and that of LA high  
11 compared to current recommendations and compared to the content in human milk from  
12 Danish mothers. In the present study the structure analyses of the formulas showed that there  
13 was a discrepancy between the locations of the fatty acids in formula fats compared with that  
14 in human milk. In contrast to human milk, 16:0 in infant formulas was located primarily in  
15 the outer positions of the triacylglycerol molecules, which may increase the risk of  
16 constipation. Only few formulas contained LCPUFA, most of which was located in the outer  
17 position of the triacylglycerol molecules, and thus at potential risk of slow and low  
18 absorption.

19

20

## 1    **ACKNOWLEDGMENTS**

2    The authors thank Karen Jensen and Zahra Roudaki for technical assistance. This study was  
 3    financed by FOETEK - The Danish Research and Development Program for Food and  
 4    Technology.

## 6    **ABBREVIATIONS**

7    ARA	Arachidonic acid
8    DHA	Docosahexaenoic acid
9    FAME	Fatty acid methyl esters
10    LA	Linoleic acid
11    LCPUFA	Long-chain polyunsaturated fatty acid
12    LNA	$\alpha$ -linolenic acid
13    MCFA	Medium-chain fatty acid
14    PUFA	Polyunsaturated fatty acid

## 17    **REFERENCES**

- 18    1. Hoffman D R, Birch EE, Castañeda YS, et al. Visual function in breast-fed term infants weaned to  
 19    formula with or without long-chain polyunsaturates at 4 to 6 months: A randomized clinical trial.  
 20    *J Pediatr* 2003;142:669-77.
- 21    2. Lauritzen L, Hansen HS, Jørgensen MH, et al. The essentiality of long-chain *n*-3 fatty acids in  
 22    relation to development and function of the brain and retina. *Prog Lipid Res* 2001;40:1-94.
- 23    3. Lucas A, Quinlan P, Abrams S, et al. Randomised controlled trial of synthetic triglyceride milk  
 24    formula for preterm infants. *Arch Dis Child* 1997;77:F178-F184.

- 1     4. Carnielli VP, Luijendijk IHT, Goudoever JB van, et al. Structural position and amount of palmitic  
2       acid in infant formulas: Effects on fat, fatty acid and mineral balance. *J Pediatr Gastroenterol*  
3       *Nutr* 1996;23:553-60.
- 4     5. Lien EL. The role of fatty acid composition and positional distribution in fat absorption in infants.  
5       *J Pediatr* 1994;125:s62-S68.
- 6     6. Jensen RG, Ferris AM, Lammi-Keefe CJ, et al. Lipids of bovine and human milks: A comparison.  
7       *J. Dairy Sci.* 1990;73:223-240.
- 8     7. Freeman CP, Jack EL, Smith LM. Intramolecular fatty acid distribution in the milk fat  
9       triglycerides of several species. *J Dairy Sci* 1965;48:853-8.
- 10    8. Mattson FH, Lutton ES. The specific distribution of fatty acids in the glycerides of animal and  
11       vegetable fats. *J Biol Chem* 1958;233:868-71.
- 12    9. Innis SM, Dyer R, Nelson CM. Evidence that palmitic acid is absorbed as *sn*2 monoacylglycerol  
13       from human milk by breast-fed infants. *Lipids* 1994;29:541-5.
- 14    10. Hamosh, M, Salem N Jr. Long-chain polyunsaturated fatty acids. *Biol. Neonate* 1998;74:106-20.
- 15    11. Report of the Scientific Committee on Food on the Revision of Essential Requirements of Infant  
16       formulae and Follow-on Formulae 2003, 69-80.
- 17    12. Clandinin MT, Van Aerde JE, Merkel KL, et al. Growth and development of preterm infant  
18       formulas containing docosahexaenoic acid and arachidonic acid. *J Pediatr* 2005;146:461-468.
- 19    13. Heird WC, Lapillonne A. The role of essential fatty acids in development. *Annu Rev Nutr*  
20       2005;25: 23.1-23.23.
- 21    14. Martin JC, Bougnoux P, Antoine JM et al. Triacylglycerol structure of human colostrum and  
22       mature milk. *Lipids* 1993;28:637-643.

- 1     15. Folch, J, Lees M, Stanley GHS. A simple method for the isolation and purification of total lipids  
2        from animal tissue. *J Biol Chem* 1957;226:497-509.
- 3     16. Christopherson SW, Glass RL. Preparation of milk fat methyl esters by alcoholysis in an essential  
4        nonalcoholic solution. *J Dairy Sci* 1969;52:1289-90.
- 5     17. Becker CC, Rosenquist A, Hoelmer G. Regiospecific analysis of triacylglycerols using allyl  
6        magnesium bromide. *Lipids* 1993;28:147-9.
- 7     18. Bracco U. Effect of triglyceride structure on fat absorption. *Am J Clin Nutr* 1994;60:1002S-9S.
- 8     19. Lauritzen L, Jørgensen MH, Hansen HS et al. Fluctuations in human milk long-chain PUFA levels  
9        in relation to dietary fish intake. *Lipids* 2002;37:237-244.
- 10    20. Carnielli VP, Luijendijk IHT, van Goudoever J.B, et al. Feeding premature newborn infants  
11        palmitic acid in amounts and stereoisomeric position similar to that of human milk: Effects on fat  
12        and mineral balance. *Am J Clin Nutr* 1995; 61:1037-1042.
- 13    21. Lien EL, Boyle FG, Yuhas R, et al. The effect of triglyceride positional distribution on fatty acid  
14        absorption in rats. *J. Pediatr Gastroenterol Nutr* 1997;25:167-74.
- 15    22. Rodriguez M, Funke S, Fink M, et al. Plasma fatty acids and [<sup>13</sup>C]linoleic acid metabolism in  
16        preterm infants fed a formula with medium-chain triglycerides. *J Lipid Res* 2003;44:41-8.
- 17    23. Jensen CN, Buist RM, Wilson T. Absorption of individual fatty acids from long-chain or  
18        medium-chain triglycerides in very small infants. *Am J Clin Nutr* 1986;43:745-51.
- 19    24. Sulkers EJ, Goudoever JB, Leunisse C, et al. Comparison of two Preterm Formulas with or  
20        without addition of medium-chain triglycerides (MCTs). I: Effects on nitrogen and fat balance  
21        and body composition changes. *J Pediatr Gastroenterol Nutr* 1992;15:34-41.
- 22    25. Christensen MS, Müllertz A, Høy C-E. Absorption of Triglycerides with Defined or Random  
23        Structure by Rats with Biliary and Pancreatic Diversion. *Lipids* 1995;30:521-6.

- 1 26. Straarup EM, Høy CE. Structured lipids improve fat absorption in normal and malabsorbing rats.  
2 *J Nutr* 2000; 130:2802-8.
- 3 27. Straarup EM, Danielsen V, Jakobsen K et al. Fat digestibility, nitrogen retention, and fatty acid  
4 profiles in blood and tissues from post-weaning piglets fed interesterified fats. *J Anim Feed Sci*  
5 2003;12:539-59.
- 6 28. Nordic Nutrition Recommendations 2004; Nord 2004:13. Nordic Council of Ministers,  
7 Copenhagen
- 8 29. Aggett PJ, Haschke F, Heine W, et al. Comment on the content and composition of lipids in infant  
9 formulas. *Acta Paediatr Scand* 1991;80:887-96.
- 10 30. Makrides M, Neumann MA, Jeffrey NM, et al. A randomized trial of different ratios of linoleic to  
11  $\alpha$ -linolenic acid in the diet of term infants: Effects of visual function and growth. *Am J Clin Nutr*  
12 2000;71:120-9.
- 13 31. Blank C, Neuman MA, Makrides M, et al. Optimizing DHA levels in piglets by lowering the  
14 linoleic acid to  $\alpha$ -linolenic acid ratio. *J Lipid Res* 2002;43:1537-43.
- 15 32. Gibson RA. Docosahexaenoic acid (DHA) accumulation is regulated by the polyunsaturated fat  
16 content of the diet: Is it synthesis or is it incorporation? *Asia Pac J Clin Nutr* 2004;13:S78.
- 17 33. Jørgensen MH, Lassen A, Michaelsen KF. Fatty acid composition in Danish in formula compared  
18 to human milk. *Scand J Nutr* 1995;39:50-4.
- 19 34. Dutta-Roy AK. Transport mechanisms for long-chain polyunsaturated fatty acids in human  
20 placenta. *Am J Clin Nutr* 2000;71 (suppl.):315S-322S.

21 .

22

**Table 2.** *The fatty acid profiles and composition in the sn2-position of triacylglycerols of human milk, cow's milk and infant formulas intended for preterm infants<sup>a</sup>*

	Human milk				Cow's milk	Standard preterm formula				
	Pooled sample Preterm milk	Innis et al (9) 3 mo after elivery	Jensen et al (6) Mature milk	Martin et al (14) Colostrum		Enfalac	Pre-Aptamil	Pre-Babymin A	Pre-Babymin B	Pre-NAN
Triacylglycerol										
8:0 <sup>b</sup>	0.2				<b>1.1</b>	<b>22.3</b>	<b>2.3</b>	<b>0.7</b>	<b>2.0</b>	<b>15.8</b>
10:0	1.4		2.9	0.4	2.8	<b>12.1</b>	1.7	1.3	1.5	<b>10.6</b>
12:0	5.7	4.1	7.3	4.8	3.4	1.6	<b>13.5</b>	5.2	<b>11.4</b>	0.5
14:0	6.9	5.5	9.4	8.5	<b>11.1</b>	1.0	5.6	5.8	4.7	0.7
16:0	25.7	21.0	27.0	25.8	<b>32.3</b>	6.1	15.9	<b>28.6</b>	17.1	11.2
16:1	2.8	3.1	3.6	3.2	2.1	0.1	0.5	1.1	0.5	0.3
18:0	8.1	7.1	7.1	5.9	<b>11.2</b>	2.5	4.4	6.8	4.5	3.0
18:1t	0.7				<b>2.9</b>	-	0.2	0.3	0.1	-
18:1n-9	33.1	40.2	34.2	32.6	20.7	29.0	<b>40.4</b>	33.4	37.3	35.9
18:1n-7	1.8				0.6	0.7	1.0	0.9	1.0	1.0
18:2 n-6	9.5	13.4	7.9	13.2	1.8	<b>20.5</b>	11.9	12.5	<b>16.8</b>	<b>16.7</b>
18:3 n-3	1.1	1.5	trace	0.7	0.2	1.8	1.3	0.9	1.4	2.2
20:4n-6	0.4	0.5		0.6	-	<b>0.8</b>	0.4	0.3	0.3	0.2
22:6n-3	0.4	0.2		0.5	-	0.4	0.2	0.2	0.2	0.3
others	2.3	1.2		3.5	<b>9.8</b>	1.2	0.6	2.1	1.2	1.4
18:2n-6/18:3n-3	8.8	8.9		18.9	9.9	11.6	9.3	14.3	12.2	7.6
<i>sn</i> -2 position										
8:0	0.2				<b>0.8</b>	<b>21.3</b>	0.2	0.1	0.1	<b>13.6</b>
10:0	0.9		1.6	0.4	<b>3.3</b>	<b>12.9</b>	0.9	1.1	0.7	<b>11.7</b>
12:0	6.1	2.5	6.9	3.8	4.9	2.7	<b>24.0</b>	6.4	<b>19.7</b>	0.8
14:0	12.0	6.2	15.4	11.1	<b>18.0</b>	0.8	3.6	9.1	2.9	0.9



16:0	57.1	54.2	57.1	53.5	37.8	1.2	3.3	19.4	4.7	3.7
16:1	2.9	3.5	1.6	3.2	2.6	0.1	0.3	1.1	0.3	0.3
18:0	1.6	2.9	4.9	1.7	<b>5.5</b>	0.3	0.6	2.7	0.7	0.7
18:1t	-				<b>2.3</b>	-	<b>0.1</b>	<b>0.2</b>	<b>0.1</b>	-
18:1n-9	9.5	17.1	8.1	13.8	15.3	<b>31.8</b>	<b>45.5</b>	<b>39.1</b>	<b>44.0</b>	<b>41.2</b>
18:1n-7	0.7				0.4	0.3	0.5	0.6	0.6	0.2
18:2n-6	5.4	8.1	3.7	8.4	1.8	<b>25.5</b>	<b>18.7</b>	<b>17.7</b>	<b>24.3</b>	<b>23.0</b>
18:3n-3	0.5	0.9		0.4	0.4	<b>1.5</b>	<b>2.1</b>	0.8	<b>1.6</b>	<b>3.1</b>
20:4n-6	0.3	0.7		0.7	-	0.7	0.1	0.1	0.1	-
22:6n-3	0.6	0.4		0.7	-	0.6	-	-	-	0.3
Others	1.7	0.9		3.4	<b>6.9</b>	0.3	0.2	1.5	0.3	0.4

<sup>a</sup>Data represent the average of two determinations for triacylglycerols and 3-4 determinations of the sn2-position and are expressed in wt% of total fatty acids in triacylglycerol or the sn2-position, respectively.

<sup>b</sup>Fatty acids are designated by the number of carbon atoms followed by the number of double bonds. The position of the first double bond relative to the methyl (n) end of the molecule is also indicated.

Values in **bold** are higher than the range of human milk values and values in *italic* are lower.

**Table 3.** *The fatty acid profiles and composition in the sn2-position in triacylglycerols of infant formula fat<sup>a</sup>*

	Standard infant formula for term infants								Follow-on formula (from 4 months)			
	Allomin	Aptamil	Baby Milk (liquid)	Babymin	HIPP-1	NAN-1 new	Nidina	Soured Allomin	Allomin-2	Allomin + rice flour	HIPP-2	NAN-2
Triacylglycerol												
8:0 <sup>b</sup>	<b>0.4</b>	<b>1.2</b>	<b>1.0</b>	<b>2.1</b>	-	<b>1.6</b>	<b>2.1</b>	<b>0.5</b>	-	<b>0.5</b>	-	<b>1.2</b>
10:0	0.9	1.4	1.7	1.7	0.1	1.1	1.2	1.0	-	1.1	0.1	0.9
12:0	1.3	6.0	3.6	<b>13.6</b>	0.2	<b>8.5</b>	<b>8.5</b>	1.4	0.2	1.4	0.2	7.0
14:0	4.4	5.8	7.0	5.7	0.9	3.9	4.0	4.7	0.7	4.7	0.9	3.3
16:0	<b>29.1</b>	26.6	<b>31.7</b>	15.9	<b>29.7</b>	24.7	24.0	<b>28.9</b>	<b>28.6</b>	<b>30.8</b>	<b>31.4</b>	22.3
16:1	0.7	1.1	1.1	0.5	0.2	0.2	0.2	0.7	0.2	0.8	0.2	0.2
18:0	6.8	6.3	7.7	4.4	3.8	3.3	3.2	7.2	4.1	6.3	3.8	3.7
18:1t	<b>1.5</b>	-	<b>1.2</b>	-	-	-	-	<b>1.6</b>	-	-	-	-
18:1n-9	33.6	34.7	29.5	40.2	<b>41.0</b>	<b>36.6</b>	<b>37.1</b>	<b>34.7</b>	<b>41.7</b>	<b>34.2</b>	40.2	37.2
18:1n-7	1.7	1.2	0.9	1.0	1.3	1.1	1.1	1.6	1.2	1.0	1.2	<b>1.9</b>
18:2n-6	<b>15.6</b>	11.2	10.0	11.9	<b>18.9</b>	<b>16.2</b>	<b>15.5</b>	<b>13.5</b>	<b>19.5</b>	12.7	<b>18.6</b>	<b>19.2</b>
18:3n-3	1.8	1.7	1.2	1.3	1.9	2.0	1.6	1.5	1.9	1.4	1.7	2.4
20:4n-6	-	0.3	0.1	0.4	-	-	-	-	-	-	-	-
22:6n-3	-	0.2	-	0.2	-	-	-	-	-	-	-	-
others	2.3	2.2	3.3	1.1	2.1	0.8	1.5	2.7	1.9	<b>5.1</b>	1.8	0.8
18:2n-6/18:3n-3	8.5	6.5	8.5	9.2	10.0	8.1	9.5	9.1	10.1	9.0	11.2	8.1
sn2-position												
8:0	<b>0.5</b>	<b>0.3</b>	0.2	0.2	-	<b>0.4</b>	0.2	-	-	0.1	-	-
10:0	0.7	0.9	1.6	0.8	-	0.5	0.6	0.5	-	0.6	-	-

12:0	<i>1.4</i>	<b>9.4</b>	5.8	<b>23.6</b>	<i>0.2</i>	<b>13.9</b>	<b>14.3</b>	<i>1.6</i>	<i>0.1</i>	<i>1.1</i>	<i>0.2</i>	4.4
14:0	6.9	7.2	11.2	<i>3.6</i>	<i>0.7</i>	<i>2.1</i>	<i>2.4</i>	7.1	<i>0.6</i>	<i>3.9</i>	<i>0.7</i>	<i>1.7</i>
16:0	<i>20.7</i>	<i>16.6</i>	<i>26.3</i>	<i>3.4</i>	<i>10.3</i>	<i>5.3</i>	<i>5.6</i>	<i>18.4</i>	<i>9.3</i>	<i>14.4</i>	<i>12.3</i>	<i>6.0</i>
16:1	<i>0.8</i>	<i>1.1</i>	<i>1.4</i>	<i>0.3</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.9</i>	-	<i>0.5</i>	<i>0.1</i>	-
18:0	3.6	2.6	3.4	<i>0.6</i>	<i>0.6</i>	<i>0.7</i>	<i>0.5</i>	3.0	1.8	2.1	<i>0.8</i>	<i>0.9</i>
18:1t	<b>1.3</b>	-	<b>1.0</b>	-	-	-	-	<b>1.3</b>	-	-	-	-
18:1n-9	<b>39.1</b>	<b>40.1</b>	<b>31.2</b>	<b>46.0</b>	<b>54.2</b>	<b>49.1</b>	<b>48.0</b>	<b>44.2</b>	<b>55.3</b>	<b>48.2</b>	<b>53.2</b>	<b>52.1</b>
18:1n-7	<i>0.6</i>	<i>0.6</i>	<i>0.5</i>	<i>0.5</i>	<i>0.6</i>	<i>0.6</i>	<i>0.5</i>	-	<i>0.6</i>	<i>0.6</i>	<i>0.6</i>	<b>0.8</b>
18:2n-6	<b>21.1</b>	<b>17.4</b>	<b>13.9</b>	<b>18.6</b>	<b>29.0</b>	<b>24.5</b>	<b>23.9</b>	<b>19.7</b>	<b>27.0</b>	<b>22.5</b>	<b>27.4</b>	<b>30.0</b>
18:3n-3	<b>2.6</b>	<b>2.3</b>	<b>1.5</b>	<b>2.1</b>	<b>3.1</b>	<b>2.9</b>	<b>2.6</b>	<b>2.1</b>	<b>2.7</b>	<b>2.3</b>	<b>2.7</b>	<b>4.0</b>
20:4n-6	-	<i>0.1</i>	-	<i>0.1</i>	-	-	-	-	-	-	-	-
22:6n-3	-	-	-	-	-	-	-	-	-	-	-	-
Others	<i>0.7</i>	1.4	1.9	<i>0.3</i>	1.2	-	1.3	1.2	2.6	<b>3.8</b>	1.9	-

<sup>a</sup>Data represent the average of two determinations for triacylglycerols and 3-4 determinations of the sn2-position and are expressed in wt% of total fatty acids in triacylglycerol or the sn2-position, respectively.

<sup>b</sup>Fatty acids are designated by the number of carbon atoms followed by the number of double bonds. The position of the first double bond relative to the methyl (n) end of the molecule is also indicated.

Values in **bold** are higher than the range of values for human milk (table 2) and values in italic are lower.

**Table 4.** *The fatty acid profiles and composition in the sn2-position of triacylglycerols of foods for special medical purpose<sup>a</sup>*

	<i>Foods for special medical purpose</i>										<i>Other foods</i>
	Generaid plus	Monogen	NAN H.A.	Neocate	Nutramigen	Nutramigen 2	Pregestimil	Profylac	Prosobee	Super Soluble Duocal	Therapeutic milk
Triacylglycerol											
8:0 <sup>b</sup>	<b>23.5</b>	<b>51.5</b>	<b>1.2</b>	<b>2.2</b>	<b>1.4</b>	<b>1.5</b>	<b>35.4</b>	-	<b>1.4</b>	<b>23.3</b>	<b>3.9</b>
10:0	<b>5.6</b>	<b>33.7</b>	<b>1.0</b>	<b>1.7</b>	<b>1.1</b>	<b>1.1</b>	<b>16.4</b>	-	<b>1.2</b>	<b>5.8</b>	2.8
12:0	<b>13.6</b>	<i>0.5</i>	<b>7.8</b>	<b>13.0</b>	<b>9.1</b>	<b>8.8</b>	<i>0.1</i>	<i>0.3</i>	<b>9.5</b>	<b>13.8</b>	<b>22.2</b>
14:0	<i>5.4</i>	<i>0.6</i>	<i>3.8</i>	<i>5.2</i>	<i>4.2</i>	<i>3.9</i>	-	<i>0.8</i>	<i>4.3</i>	<i>5.5</i>	<b>9.5</b>
16:0	<i>8.3</i>	<i>2.7</i>	<i>24.3</i>	<i>8.3</i>	<i>22.6</i>	<i>22.9</i>	<i>4.4</i>	<b>27.7</b>	<i>22.2</i>	<i>7.9</i>	<i>25.6</i>
16:1	<i>0.1</i>	-	<i>0.2</i>	-	<i>0.1</i>	<i>0.1</i>	-	<i>0.2</i>	<i>0.1</i>	<i>0.2</i>	-
18:0	<i>2.7</i>	<i>2.0</i>	<i>4.0</i>	<i>4.1</i>	<i>3.7</i>	<i>3.8</i>	<i>1.4</i>	<i>3.3</i>	<i>4.1</i>	<i>2.4</i>	<b>8.4</b>
18:1t	<i>0.3</i>	-	-	-	-	-	-	<i>0.4</i>	-	-	<b>1.3</b>
18:1n-9	<i>13.7</i>	<i>2.6</i>	<i>35.8</i>	<b>46.6</b>	<i>37.9</i>	<i>36.5</i>	<i>20.3</i>	<b>48.2</b>	<i>36.2</i>	<i>13.8</i>	<i>20.0</i>
18:1n-7	<i>0.3</i>	-	<i>1.8</i>	<i>0.6</i>	<i>1.4</i>	<i>0.8</i>	<i>0.4</i>	<b>2.2</b>	<i>0.8</i>	<i>0.3</i>	-
18:2n-6	<b>25.2</b>	<i>5.3</i>	<b>17.1</b>	<b>16.3</b>	<b>17.1</b>	<b>18.3</b>	<b>20.1</b>	<b>14.5</b>	<b>17.7</b>	<b>26.0</b>	<i>5.2</i>
18:3n-3	<i>0.7</i>	<i>1.0</i>	<i>2.0</i>	<i>1.0</i>	<i>1.2</i>	<i>1.4</i>	<i>1.0</i>	<i>1.7</i>	<i>1.8</i>	<i>0.5</i>	<i>0.3</i>
20:4n-6	-	-	-	-	-	-	-	-	-	-	-
22:6n-3	-	-	-	-	-	-	-	-	-	-	-
Others	<i>0.4</i>	-	<i>1.0</i>	<i>0.9</i>	<i>0.1</i>	<i>1.0</i>	<i>0.5</i>	<i>0.7</i>	<i>0.7</i>	<i>0.6</i>	<i>0.7</i>
18:2n-6/18:3n-3	<b>36.4</b>	<i>5.5</i>	<i>8.4</i>	<b>16.8</b>	<i>14.5</i>	<i>13.5</i>	<b>20.3</b>	<i>8.7</i>	<i>9.9</i>	<b>54.8</b>	<b>17.8</b>
sn2-position											
8:0	<b>20.4</b>	<b>52.0</b>	-	<i>0.2</i>	<i>0.1</i>	<i>0.2</i>	<b>36.1</b>	-	<b>0.4</b>	<b>22.7</b>	-
10:0	<b>5.6</b>	<b>39.0</b>	-	<i>0.9</i>	<i>0.4</i>	<i>0.4</i>	<b>19.6</b>	-	<i>0.6</i>	<b>5.9</b>	<i>1.0</i>
12:0	<i>25.7</i>	<i>0.9</i>	<b>5.8</b>	<b>23.7</b>	<b>14.6</b>	<b>14.6</b>	<i>0.1</i>	-	<b>15.8</b>	<b>23.5</b>	<b>35.5</b>
14:0	<i>3.3</i>	<i>1.1</i>	<i>1.8</i>	<i>3.2</i>	<i>2.4</i>	<i>2.4</i>	-	<i>0.2</i>	<i>2.1</i>	<i>2.9</i>	<i>5.1</i>
16:0	<i>2.3</i>	<i>2.1</i>	<i>5.7</i>	<i>3.0</i>	<i>6.2</i>	<i>6.1</i>	<i>0.4</i>	<i>5.0</i>	<i>4.9</i>	<i>1.4</i>	<i>10.1</i>
16:1	<i>0.1</i>	-	<i>0.2</i>	-	-	-	-	<i>0.1</i>	<i>0.1</i>	-	-
18:0	<i>1.7</i>	<i>1.9</i>	<i>0.6</i>	<i>2.6</i>	<i>1.4</i>	<i>1.4</i>	<i>0.1</i>	<i>0.7</i>	<i>0.5</i>	<i>1.2</i>	<b>6.7</b>
18:1t	<i>0.3</i>	-	-	-	-	-	-	<b>0.6</b>	-	-	<b>1.7</b>
18:1n-9	<i>12.7</i>	<i>1.1</i>	<b>52.3</b>	<b>46.9</b>	<b>50.8</b>	<b>50.6</b>	<b>19.8</b>	<b>63.6</b>	<b>49.2</b>	<b>13.0</b>	<b>30.1</b>
18:1n-7	<i>0.1</i>	-	<b>1.3</b>	-	<i>0.4</i>	<i>0.4</i>	<i>0.2</i>	<b>1.3</b>	<i>0.4</i>	<i>0.1</i>	-
18:2n-6	<i>27.4</i>	<i>1.6</i>	<b>28.6</b>	<b>18.7</b>	<b>22.5</b>	<b>22.5</b>	<b>22.8</b>	<b>26.0</b>	<b>25.0</b>	<b>28.9</b>	<b>9.4</b>
18:3n-3	<i>0.4</i>	<i>0.3</i>	<b>3.7</b>	<b>0.8</b>	<b>1.0</b>	<b>1.0</b>	<b>0.8</b>	<b>2.5</b>	<b>1.1</b>	<i>0.4</i>	<i>0.5</i>
20:4n-6	-	-	-	-	-	-	-	-	-	-	-
22:6n-3	-	-	-	-	-	-	-	-	-	-	-
Others	-	-	<i>0.1</i>	-	-	<i>0.3</i>	<i>0.1</i>	-	-	-	-

<sup>a</sup>Data represent the average of two determinations for triacylglycerols and 3-4 determinations of the sn2-position and are expressed in wt% of total fatty acids in triacylglycerol or the sn2-position, respectively.<sup>b</sup>Fatty acids are designated by the number of carbon atoms followed by the number of double bonds. The position of the first double bond relative to the methyl (n) end of the molecule is also indicated.Values in **bold** are higher than for human milk and values in italic are lower.

**Table 1.** *List of infant formulas and foods for special medical purpose, the year they were purchased, manufacturer and type and indications for special medical foods.*

Formula	Purchased	Manufacturer
<i>Formula for preterm infants</i>		
Enfalac	2003	Mead Johnson
Pre-Aptamil	2001	Milupa GmbH
Pre-Babymin A	2000	Milupa GmbH
Pre-Babymin B	2000	Milupa GmbH
Pre-NAN	2000	Nestlé
<i>Infant formula for term infants</i>		
Allomin	2003	Beauvais
Allomin Soured	2003	Beauvais
Aptamil	2001	Milupa GmbH
Babymilk	2003	Arla
Babymin	1999	Milupa GmbH
HIPP 1	2002	HIPP GmbH & Co Vertrieb KG
NAN 1 new	2003	Nestlé
Nidina 1	2002	Nestlé
<i>Follow-on formula (from 4 months)</i>		
Allomin 2	2003	Beauvais
Allomin rice flour	2003	Beauvais
HIPP 2	2002	HIPP GmbH & Co Vertrieb KG
NAN 2	1999	Nestlé
<i>Foods for special medical purpose</i>		
Generaid Plus	1999	SHS international ( <i>For hepatic disorders, for sole source of nutrition it is recommended to supplement with a source of <math>\alpha</math>-linolenic acid</i> )
Monogen	1999	SHS international ( <i>High content of MCT for use in lipid and lymphatic disorders</i> )
NAN H.A	2003	Nestlé ( <i>Hydrolyzed protein for infants at risk of allergy</i> )
Neocate	2003	SHS international ( <i>Protein as amino acids, for cow's milk allergy and multiple food intolerance</i> )
Nutramigen	2000	Mead Johnson ( <i>Hydrolyzed protein, for prevention and treatment of cow's milk allergy</i> )
Nutramigen 2	2003	Mead Johnson ( <i>Hydrolyzed protein, for prevention and treatment of cow's milk allergy from 4 months</i> )
Pregestimil	1999	Mead Johnson ( <i>Hydrolyzed protein for fat malabsorption</i> )
Profylac	1999	Alk ( <i>Hydrolyzed protein, for prevention and treatment of cow's milk allergy</i> )
Prosobee	2001	Mead Johnson ( <i>Soy-protein, for cow's milk allergy</i> )
Super Soluble Duocal	2001	SHS international ( <i>Energy supplement with carbohydrate and fat, for liver disease and catabolic states</i> )
<i>Other foods</i>		
Therapeutic milk	1999	Compact ( <i>For "therapeutic feeding" in severely malnourished children in developing countries</i> )